

Figure F.7. Rotor-based PSC Enclosure (Top View)

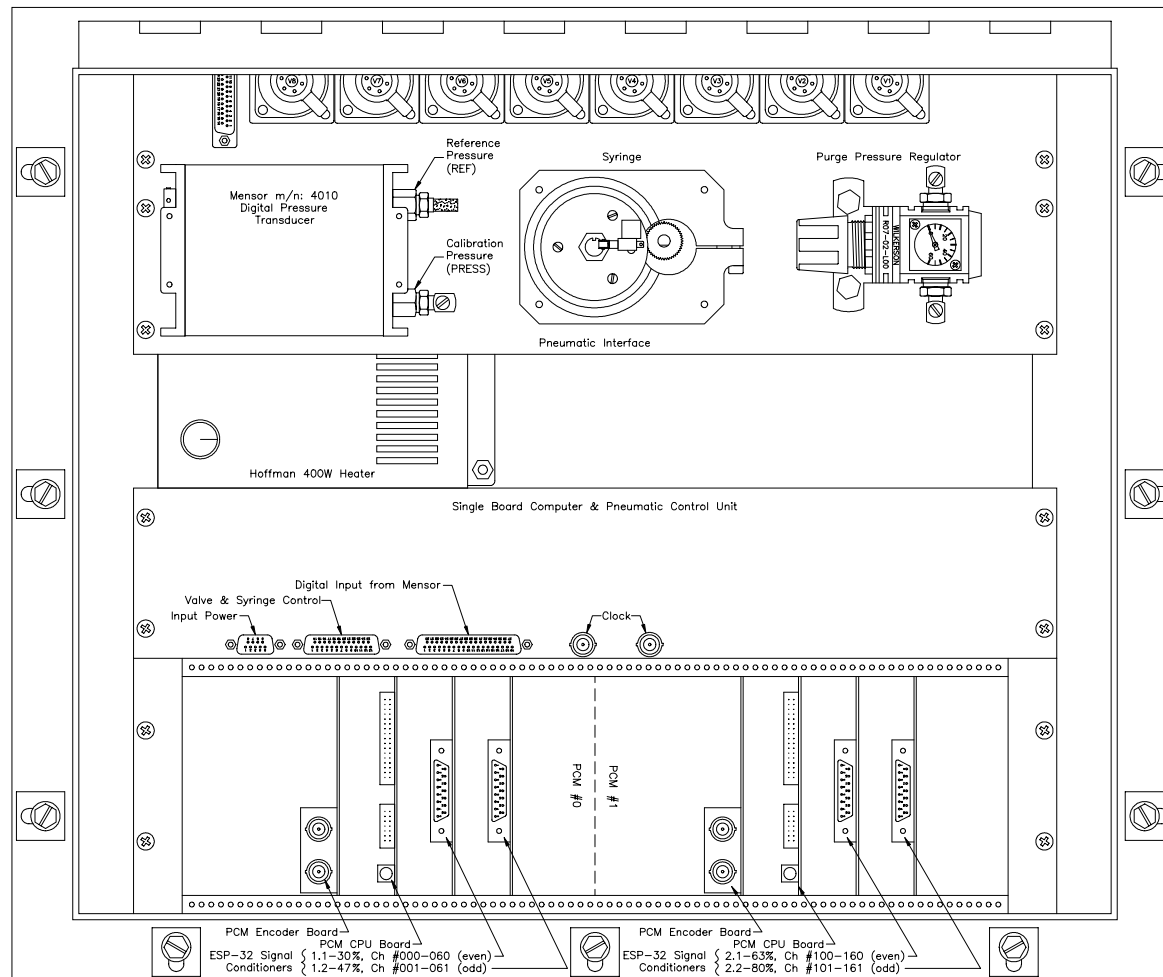


Figure F.8. Rotor-based PCM Enclosure (Side View)

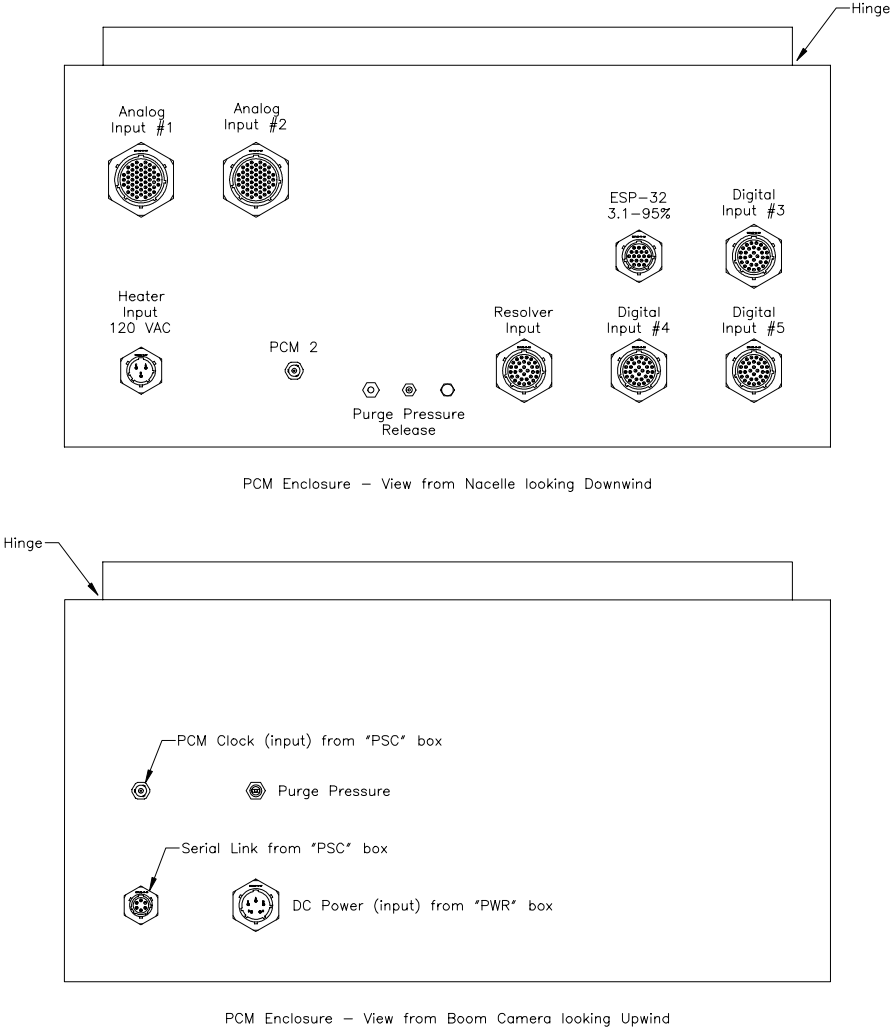


Figure F.9. Ground-based PCM Rack Power

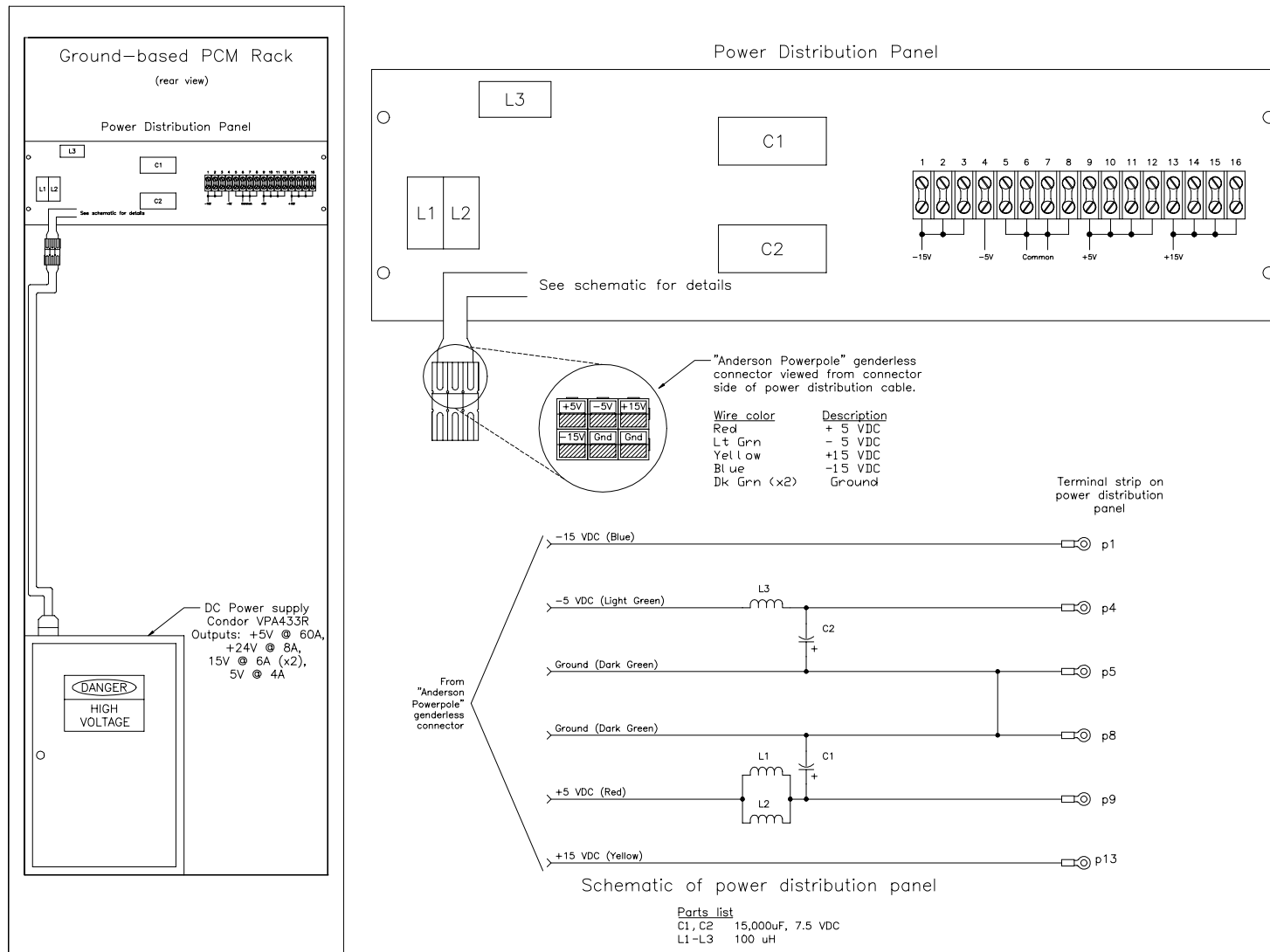


Figure F.10. Ground-based PCM rack I/O

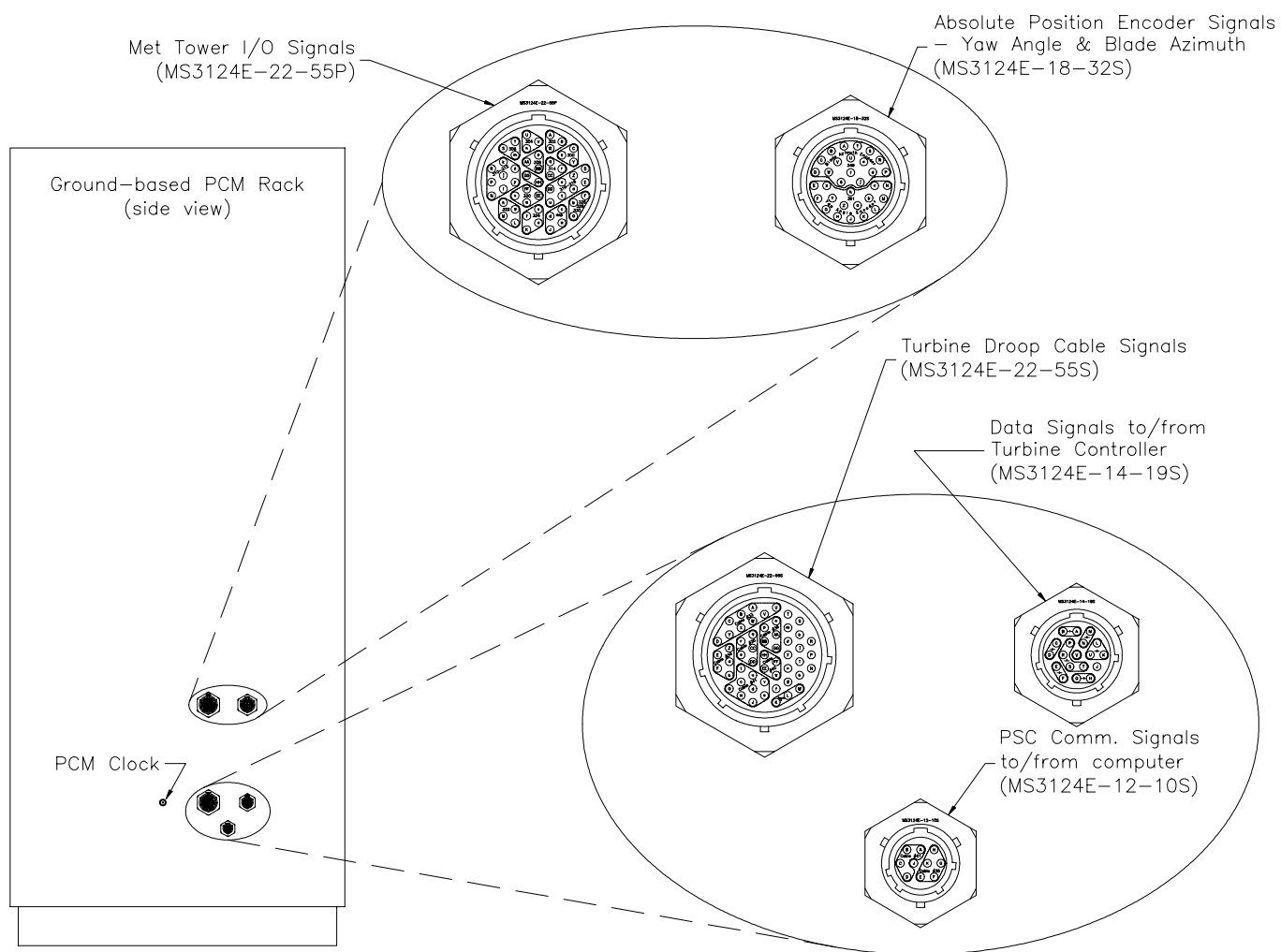


Figure F.11. Aspirator Alarm Panel Schematic

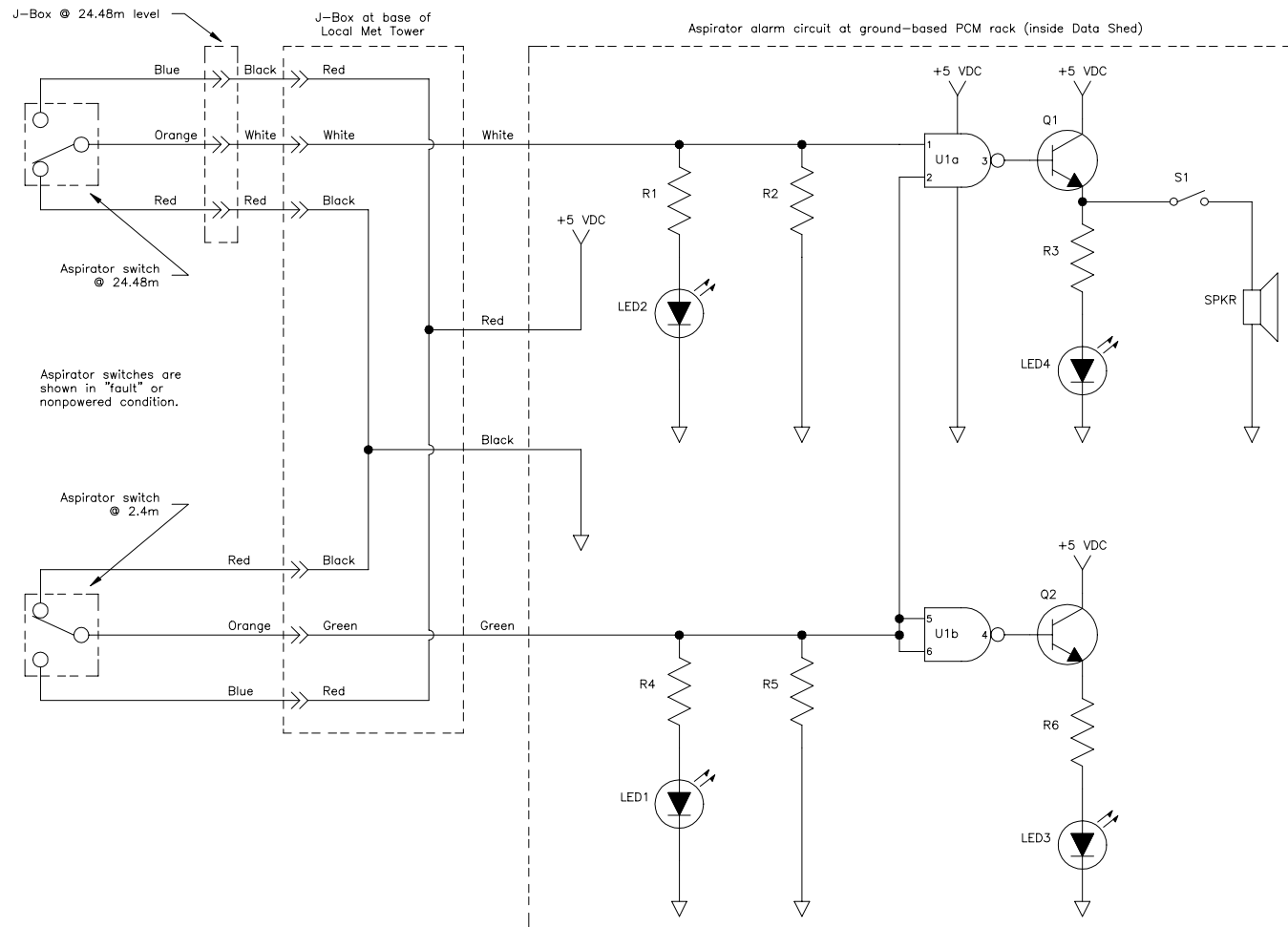


Figure F.12. Aspirator Alarm Panel Wiring

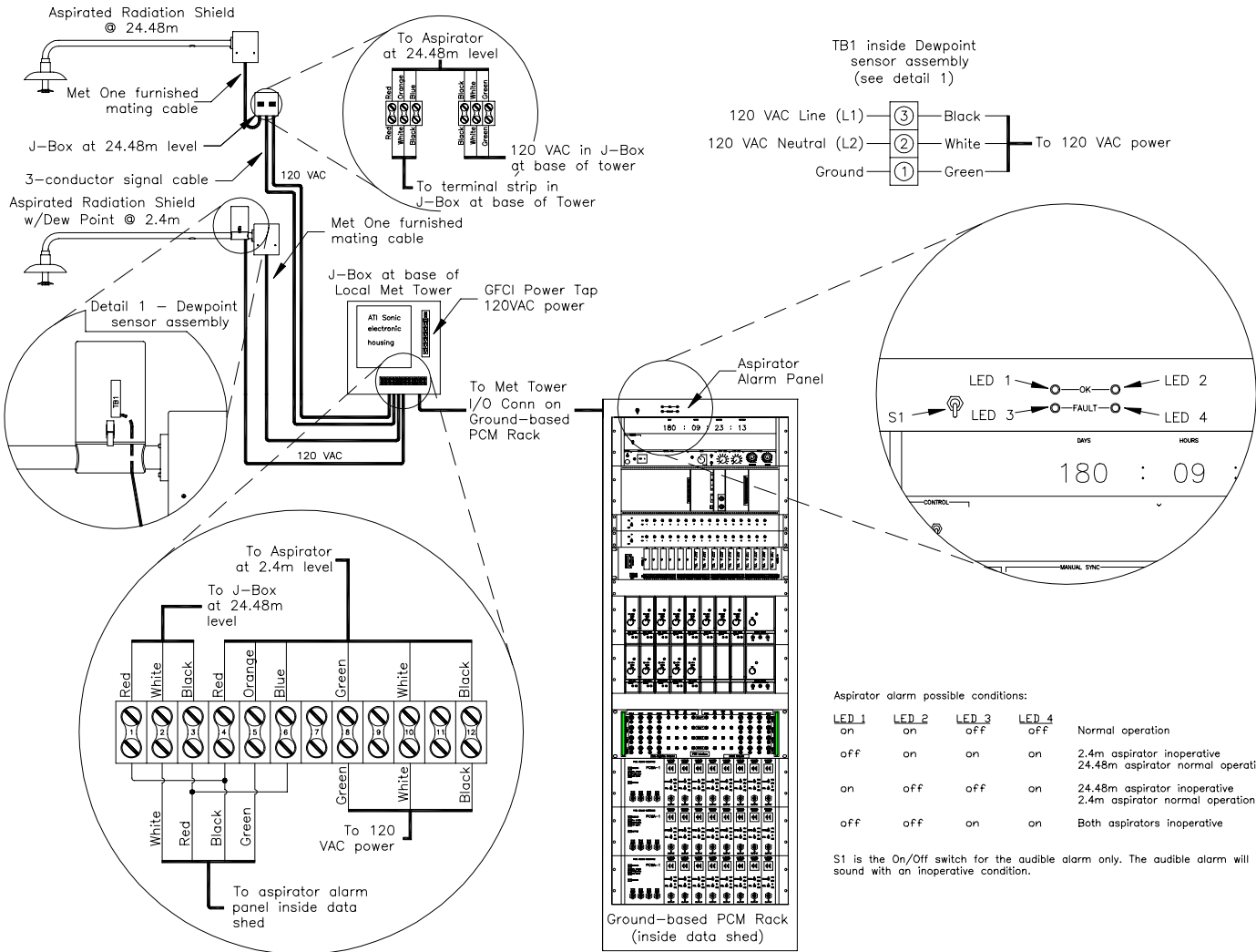
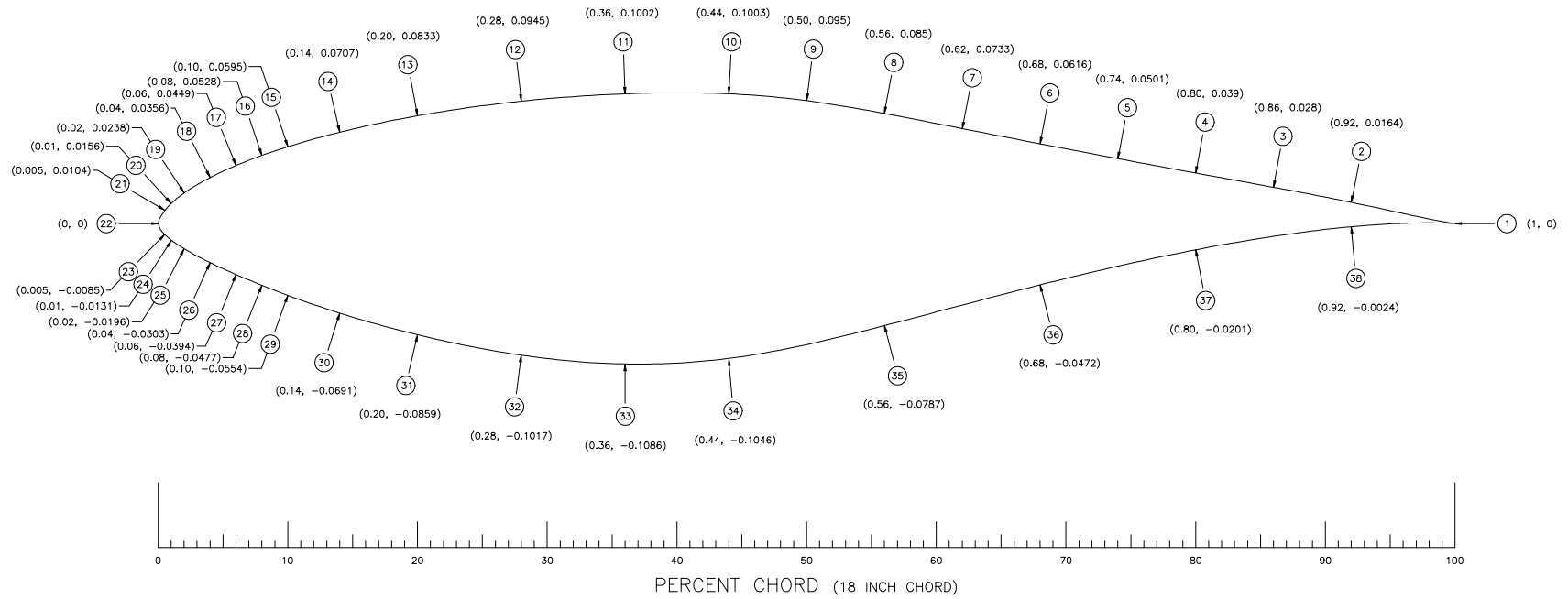


Figure F.13. Pressure Tap Layout



REFERENCES

- Butterfield, C.P.; Musial, W.P.; Simms, D.A. (1992). *Combined Experiment Phase I Final Report*. NREL/TP-257-4655. Golden, CO: National Renewable Energy Laboratory.
- Composite Engineering. (1994). "Final Design and Analysis Report." Unpublished.
- Corten, G.P. (1998). "The April 95 Procedure to Measure the Pressure Coefficient C_p on a Wind Turbine in the Field." *Aerodynamics of Wind Turbines, 12th Symposium, December 3-4, Lyngby, Denmark*. Lyngby, Denmark: Technical University of Denmark for International Energy Agency.
- Fingersh, L.J.; Robinson, M.C. (1997). "Wind Tunnel Calibration of 5-hole Pressure Probes for Application to Wind Turbines. *Proceedings of 16th ASME Wind Energy Symposium, January 6-9, Reno, NV*. New York: American Institute for Aeronautics and Astronautics.
- Hand, M.M. (1999). *Conversion of Phase II Unsteady Aerodynamics Experiment Data to Common Format*. NREL/TP-500-26371. Golden, CO: National Renewable Energy Laboratory.
- Huyer, S.A.; Simms, D.A.; Robinson, M.C. (1996). "Unsteady Aerodynamics Associated with a Horizontal-Axis Wind Turbine." *American Institute of Aeronautics and Astronautics Journal*, Volume 34, No. 10.
- Huyer, S.A. (1993). *Examination of Forced Unsteady Separated Flow Fields on a Rotating Wind Turbine Blade*. NREL/TP-442-4864. Golden, CO: National Renewable Energy Laboratory.
- McNiff, B.; Simms, D. (1992). "Error Analysis in Wind Turbine Field Testing." *Windpower '92 Proceedings, October 22-23, Seattle, Washington*. Washington, D.C.: American Wind Energy Association.
- Pope, A.; Harper, J. (1966). *Low-Speed Wind Tunnel Testing*. New York. Wiley & Sons.
- Rae and Pope. (1984). *Low-Speed Wind Tunnel Testing*. New York: Wiley & Sons.
- Scott, G.N. (1996). "PDIS Pressure Display Program Technical Description." Unpublished.
- Shipley, D.E.; Miller, M.S.; Robinson, M.C.; Luttgies, M.W.; Simms, D.A. (1995). *Techniques for the Determination of Local Dynamic Pressure and Angle of Attack on a Horizontal Axis Wind Turbine*. NREL/TP-442-7393. Golden, CO: National Renewable Energy Laboratory.
- Simms, D.A.; Robinson, M.C.; Hand, M.M.; Fingersh, L.J. (1996). "Characterization and Comparison of Baseline Aerodynamic Performance of Optimally-Twisted Versus Non-Twisted HAWT Blades." Prepared for 15th ASME Wind Energy Symposium, January, 1996. NREL/TP-442-20281. Golden, CO: National Renewable Energy Laboratory.
- Simms, D.A.; Fingersh, L.J.; Butterfield, C.P. (1995). "NREL Unsteady Aerodynamics Experiment Phase III Test Objectives and Preliminary Results." *Proceedings of ASME/ETCE Conference, January 29-February 1, Houston, Texas*. New York: ASME.
- Simms, D.A.; Butterfield, C.P. (1991). *A PC-Based Telemetry System for Acquiring and Reducing Data from Multiple PCM Streams*. SERI/TP-257-4123. Golden, CO: Solar Energy Research Institute (now known as National Renewable Energy Laboratory).
- Simms, D.A.; Butterfield, C.P. (1990). *PC-Based PCM Telemetry Data Reduction System Hardware*. SERI/TP-257-3662. Golden, CO: Solar Energy Research Institute (now known as National Renewable Energy Laboratory).

Smithsonian Institution. (1949). *Smithsonian Meteorological Tables*. Smithsonian Publication 4014. Smithsonian Institution Press: Washington, D.C. Prepared by R.J. List.

Somers, D.M. 1997. *Design and Experimental Results for the S809 Airfoil*. NREL/SR-440-6918. Golden, Colorado: National Renewable Energy Laboratory.

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13. ABSTRACT (<i>Maximum 200 words</i>) The main objective of the Unsteady Aerodynamics Experiment is to provide information needed to quantify the full-scale three-dimensional aerodynamic behavior of horizontal axis wind turbines. To accomplish this, an experimental wind turbine configured to meet specific research objectives was assembled and operated at the National Renewable Energy Laboratory (NREL). The turbine was instrumented to characterize rotating blade aerodynamic performance, machine structural responses, and atmospheric inflow conditions. Comprehensive tests were conducted with the turbine operating in an outdoor field environment under diverse conditions. Resulting data are used to validate aerodynamic and structural dynamics models which are an important part of wind turbine design and engineering codes. Improvements in these models are needed to better characterize aerodynamic response in both the steady-state post-stall and dynamic stall regimes. Much of the effort in the earlier phase of the Unsteady Aerodynamics Experiment focused on developing required data acquisition systems. Complex instrumentation and equipment was needed to meet stringent data requirements while operating under the harsh environmental conditions of a wind turbine rotor. Once the data systems were developed, subsequent phases of experiments were then conducted to collect data for use in answering specific research questions. A description of the experiment configuration used during Phases II - IV of the experiment is contained in this report.				
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